Abstract — Wireless multi-vision applications for home entertainment are becoming an important trend in consumer electronics domain. Currently, most of the existing applications rely on the 802.11g/n standards, capable to seamlessly stream HD video contents. These standards are operating in the license-free ISM band, which, due to the rapid revolution in wireless communication in past years, is becoming overexploited and experiences serious coexistence problems. The spectrum overcrowding in the free bands puts in a new light the VHF and UHF bands that are currently seen as a promising alternative spectrum resource, especially in the perspective of the worldwide switchover from analog to digital TV and in the light of the new emerging dynamic spectrum access techniques. Within this framework, this paper presents an unlicensed cognitive radio indoor multi-vision system operating in the UHF TV band for short-range indoor transmission of high definition TV contents. The system relies on a combined exclusive approach of spectrum sensing and geo-location database and is compliant with the DVB-T2 broadcasting standard. A proof-of-concept digital terrestrial television (DTT) compliant prototype has been implemented on a test-bed based on commercial DTT receivers in combination with software defined radio hardware devices. Extended measurements performed in a real indoor environment assessed the feasibility of the proposed system in terms of coverage and protection of the incumbent users.

Index Terms — TV Multi Vision System, DTT, HDTV, White Spaces, Cognitive Radio, Geolocation Databases.

I. INTRODUCTION

The evolution of wireless communication systems and networks in recent years has been explosive. This trend had an enormous impact also on short-range indoor consumer applications. Within this field, several new means for delivering services, such as TV video streaming over IP (IPTV) based either on XDSL or in the forthcoming near future on WiMAX, LTE or LTE-A access, are arising beside traditional terrestrial and satellite systems [1]. All these new access techniques are providing broadband services, enabling the streaming of high definition video and audio information on a new light the VHF and UHF bands that are currently seen as a promising alternative spectrum resource, especially in the perspective of the worldwide switchover from analog to digital TV and in the light of the new emerging dynamic spectrum access techniques. Within this framework, this paper presents an unlicensed cognitive radio indoor multi-vision system operating in the UHF TV band for short-range indoor transmission of high definition TV contents. The system relies on a combined exclusive approach of spectrum sensing and geo-location database and is compliant with the DVB-T2 broadcasting standard. A proof-of-concept digital terrestrial television (DTT) compliant prototype has been implemented on a test-bed based on commercial DTT receivers in combination with software defined radio hardware devices. Extended measurements performed in a real indoor environment assessed the feasibility of the proposed system in terms of coverage and protection of the incumbent users.

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M. Fadda and M. Murroni are with the Department of Electrical and Electronic Engineering, University of Cagliari, Cagliari 09123, Italy (e-mail: mauro.fadda@diee.unica.it; murroni@diee.unica.it)

V. Popescu is with the Department of Electronics and Computers, Transilvania University of Brasov, Brasov 500019, Romania (e-mail: vlad.popescu@unitbv.ro).

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A Cognitive Radio Indoor HDTV Multi-Vision System in the TV White Spaces

Mauro Fadda, Maurizio Murroni and Vlad Popescu, Member, IEEE

[2]. The new generation set-top boxes are provided with the multiple access feature being able to decode heterogeneous TV input signals (e.g., DVB-T, DVB-S, IPTV) whereas the promise of multi-room digital video recording, as well as the ability to deliver commercial content to more devices within the same domestic environment, excites both consumers and service providers. Within this context, the Digital Living Network Alliance (DLNA) has developed a robust set of technical guidelines for high-quality streaming of multimedia content over both wireless and wired network connections between home entertainment and mobile devices [3]. The DLNA guidelines provide for a homogeneous and universal infrastructure through Wi-Fi 802.11 for wireless connectivity and Multimedia over Coax Alliance (MoCA) for wired connections. MoCA uses an infrastructure based on coaxial cable for providing reliable distribution of video content.

Currently, most wireless in-home technologies are operating in the unlicensed 2.4 GHz Industrial Scientific and Medical (ISM) band. Spectrum sharing among these diverse technologies raises serious coexistence problems in the ISM band that may lead to performance degradation or even to network malfunctioning. These problems are even more accentuated in urban morphologies such as dense cities with near multiple floor buildings. In the EU, for instance, the proliferation of indoor Wi-Fi networks operating in the ISM band, has led to a situation in which every flat has its own Wi-Fi spot, leading to complex coexistence problems.

In order to limit this congestion, especially for indoor applications, the first proposed solution was the use of the currently non-congested 5 GHz band. Unfortunately, working at such high frequencies does not allow indoor systems to provide very high data rates and adequate coverage in indoor environment such as multi-floor houses. Therefore, a valid alternative would be to use lower frequencies (below 1 GHz), for which the signal propagation in indoor environment improves, avoiding phenomena related to the presence of objects, walls and other obstacles, even in big buildings with multiple floors.

In the USA, extended measurements performed by the Federal Communication Commission (FCC) have shown that a large part of the radio spectrum, although allocated, is virtually unused and known as spectrum “white spaces” [5]. Emblematic is the case of the current TV market using the UHF and VHF bands for regional and national TV services: worldwide, lots of countries have already finished or are in the process of switching off analog TV broadcasting in favor of Digital Terrestrial Television (DTT) broadcasting systems [6]. The resulting unused channels within this band are called “TV white spaces” (TVWS).
Even after the redistribution of the digital TV channels, the problem of an efficient utilization of the allocated frequencies is still far from being solved. For example, there are still large territorial areas on which, although allocated, the TV channels result unused, due to coverage problems. In these conditions a transmitter operating at a low antenna height and a low power level such as for a typical indoor application, could reasonably operate without causing existing interference to TV services, due to its much restrained service and interference range.

To dynamically exploit the nominated spectral opportunities (i.e., TVWS), such a device should have the capability of monitoring its own radio environment and adapt accordingly. These capabilities are typical for the new spectrum allocation approaches such as the dynamic spectrum access and cognitive radios (CR). The spectrum management rule of CRs is that all new users for the spectrum are secondary cognitive users (SUs), are able to detect and avoid primary licensed users (PUs) by adjusting functional parameters such as carrier frequency, modulation type and transmission power.

In the TV bands specifically, the presence of PUs (e.g. TV broadcasters) can be revealed both performing a local survey of the occupied spectrum (the “spectrum sensing” operation) and considering the information provided by the external databases called “geo-location databases” (GL-DBs), if available.

In the United States, the FCC has already named several operators and performed first field tests with such GL-DBs accessible to CR devices at no operational cost. The database provides, for a certain location, the list of the free TV channels and the allowable maximum effective isotropic radiated power (EIRP) for transmitting without harmful interference to incumbent users [7]. In other countries such as the UK the management of Program Making and Special Events (PMSE) band already makes extensive use of similar databases to license radio microphones and in-ear monitor (IEMs) users within the UHF band.

The drawback of using GL-DBs, even upgraded on a daily basis, resides in the values corresponding to a specific geographical point that are still the results of calculations based on a certain signal propagation model and estimated power level. Due to this static (for short term at least) approach, the provided data might be inaccurate for different reasons such as variable atmospheric conditions or multipath and fading phenomena. Furthermore, GL-DB querying is based on the exact position of a cognitive device, which especially for indoor applications may not be accurate [7]-[8].

The BBC conducted a study [9] on compatibility problems for broadcasting networks and devices operating in the DTT band. The study identified the joint use of spectrum sensing techniques, GL-DBs and EIRP control as a possible way to effective safe communications. This conclusion is being supported also by a research conducted by the Electronic Communication Committee (ECC) [10] and is implemented by the first worldwide TVWS cognitive radio standard, the IEEE 802.22 WRAN [11]-[12].

By the light of that, TVWS in the UHF bands, with respect to certain limited low power applications, could be an ideal candidate to reduce the congestion in the 2.4 GHz band for typical consumer indoor applications.

Within this framework, we propose a multi-vision indoor system for the wireless retransmission of high definition (HD) DTT-compliant contents in the TVWS, with straightforward implementations as home entertainment system. The HDTV content can be both free-to-air (FTA) and pay-per-view (PPV) channels received by either DTT/SAT or cable TV, IPTV, sources as well as auxiliary content originating external inputs (A/V devices, infotainment content, closed-circuit television, etc.). The DTT receivers do not require auxiliary hardware besides a conditional access module (CAM) nowadays commonly incorporated in consumer equipment. A potential consumer application scenario is indoor broadcasting of HD DTT contents, redirecting several channels which may be acquired from different sources (DTT, SAT, IPTV, cable TV etc.). Unauthorized access is prevented by employing digital rights management (DRM) scrambling techniques [13]-[14] implemented on a common interface (CI) card to be inserted in the CAM slot of the DTT receivers [15]. The system relies on the exclusive joint use of GL-DBs and spectrum sensing.

We focused on real transmitting constraints such as the Adjacent Channel Interference (ACI) issues, the potential direct radiation into the TV receiver and the presence of similar systems within the same coverage range. To assess the feasibility of the proposed system, extended measurements were performed in real indoor environments with respect to the protection of the existing broadcasting TV services which verify the suitability for multi-floor environments.

The rest of the paper is organized as follows. Section II describes the design of the proposed technical solution and section III presents the actual implementation. Section IV describes the test-bed, the performed measure campaign together with the results of the hardware implementation, to illustrate the system’s feasibility. Section V illustrates some application scenarios while section VI presents the conclusions and future work.
II. REDISTRIBUTION OF TV CONTENTS – DESCRIPTION

Before starting with the description of the system, the concepts of multiplex and transponder for digital television transmissions need to be introduced. A multiplex (MUX) is a group of several TV channels mixed together (multiplexed) and broadcasted over a DTT frequency. Many pay-per-view TV broadcasters offer to their subscribers several MUX packages (i.e. a dedicated MUX for sport events, movies etc.). Similar to the terrestrial MUX, the satellite transponder (S-TRAN) includes several video and audio channels on a single wideband carrier.

The main idea of the present work is to use TVWS to redirect one or more TV MUXs/transponders originating from terrestrial or satellite transmissions to a range of authorized users in an indoor environment. Auxiliary content from DVD/PC/mobile/camcorders or IPTV devices can be also redirected for home entertainment use or for infotainment architectures (resorts, hotels, airports, malls etc.).

Besides the active use of GL-DB (encouraged both by European and US regulation boards and IEEE standards), the proposed system considers also spectrum sensing as a useful and valuable complementary resource. Sensing is used for validating in an exclusive manner the local unused or underused channel information read from the database and, in case, refining the terms of their use (e.g. EIRP control).

The indoor multi-vision system is based on a central cognitive device, acting as a local server, in charge for receiving TV content and retransmitting it at low power to clients that are commercial TV sets with onboard DTT decoders (figure 1). Prior to the distribution, the entire TV content is encoded/scrambled by a proprietary Digital Rights Management (DRM) - compliant system [13]-[14], thus preventing the streaming by unauthorized users. Only the TV sets equipped with a dedicated Conditional Access Module (CAM), previously paired to the central device, will be enabled to decode and view the retransmitted contents. The four main tasks performed by the central cognitive device are illustrated in figure 2.

Receiving digital broadcasting contents and translating it from radio frequencies to baseband (RF/BB modules) is the first task performed by the central cognitive device. Each of the \( n \) modules can handle the TV channels contained in one DTT MUX or satellite transponder. Additional modules are needed for simultaneously receiving more MUXs or transponders in order to allow the users to build up a list of desired TV channels.

Based on this list, the central block (DMUX/S-TRAN/MUX) handles the \( n \) received digital contents and bundles the chosen channels into one or more MUXs/transponders compliant to a specific DTT standard. The number \( m \) of generated MUXs/S-TRANs depends on the number of the desired channels and their characteristics (SDTV, HDTV, radio etc.). The central block can also redirect additional contents from external DVD/PC/mobile/camcorders or IPTV devices (AUX streams) as one or more channels within a MUX.

The decision block handles input received from the spectrum sensing block, from the external GL-DB and from the DMUX/S-TRAN/MUX block. The scheme adopted in this work performs coarse sensing based on energy detection, followed by a feature detection performed on the signals in the sub-bands declared free by the previous stage. In order to mitigate the problems of geo-localization for indoor applications, the decision block takes into consideration possible inconsistencies between the outputs of the GL-DBs and the sensing blocks: for example, if the spectrum sensing stage detects no existing services, but the database shows that one or more channels are actively used by registered services, these channels will not be used until both content is congruous.
In the other case, if the spectrum sensing stage detects signals of broadcast services, but the database shows no used channels, the incriminated channels are discarded too [16]. The validation analysis provides the optimal frequencies and the maximum transmission power values to be used by the \( m \) BB/RF modules, based on an algorithm which will be presented in section 3.

The last task of the central cognitive devices implies the \( m \) BB/RF modules in the effective over-the-air DTT-compliant retransmission of the digital contents using the previously calculated frequencies and power levels as to avoid interferences with the incumbent services.

### III. SYSTEM DESIGN

The proposed system, using the information on the channel occupancy for a specific location, needs to determine the allowable maximum EIRP for transmitting without interfering to the adjacent channels. Real transmitting device constraints (potential direct radiation into TV receivers, ACI issues and the existence of similar devices) need to be taken into account in order to find exhaustive values.

#### A. Adjacent Channel Interference

For indoor environments the distance between an interference device and a DTT receiver is relatively short and intermodulation effects can occur. Several studies revealed that transmission on adjacent channels can cause harmful interference if the output power of the transmission exceeds the maximum received interference power tolerable by the DTT receiver [16]-[17]. Further measurements [17] have been made on a wider range of receivers in order to calculate their protection ratio. The protection ratio is the minimum value of the signal-to-interference ratio required to obtain a specified reception quality under specified conditions at the receiver input [18]. The absence of a picture failure (PF) [19]-[20], during a minimum observation time of 30 seconds was the subjective evaluation criteria for the reception quality quantification.

The first two curves (labeled “Si Tuner” and “CAN Tuner”) in figure 3 clearly show how the power of an interfering DTT signal does not decay gradually on both sides starting with the adjacent channel. The fifth and the ninth channel can create interference problems, depending on the quality of the receivers, especially for the older, so-called “CAN” tuners. Most of the current TV sets use newer “silicon” tuners having a much smoother and predictable protection ratio than CAN tuners across all channels and do not suffer from the ninth image channel weakness in protection ratio [17]. All these measurements found in the literature have been performed by coupling the useful and interferer signals directly, using directional couplers.

#### B. Anechoic Chamber Measurements

Starting from the consideration that real DTT systems implement over-the-air transmissions, we decided to play a similar measurement campaign in an ideal radio environment using antennas for the transmission of the wanted TV and interference signal. The measurements were performed in the anechoic chamber of the Department of Electrical and Electronic Engineering of the University of Cagliari in Italy. We tested three commercial DTT flat-screen TV receivers. A PC running GNU radio software was in charge to generate the wanted TV signal that was successively transmitted by an USRP2 SDR board covering the entire UHF band and connected to a CBL6143 indoor stub antenna. The TV sets were connected to a PCB WA5VJB log-periodic antenna. The DTT-compliant interference signal was generated with an Agilent N5183A signal generator using a Sirio SD 1300N discone antenna. The transmitted and received signal power was analyzed using an Agilent N9010A EXA Signal Analyzer.

![Fig. 3. DTT into DTT protection ratio (DVB-T signal, 8K 64QAM 2/3 FEC) with \( C = -73 \text{ dBm} \) for literature references (first three curves) and measurements performed in the anechoic chamber (Anechoic 1, 2, 3 curves)](image-url)
All the antennas were properly placed in the anechoic chamber at a height of 1.5 m, in order to avoid antenna coupling. Optical fiber cables were used to connect the antennas to the generators, vector analyzer and DTT receivers placed outside the chamber.

Using the guidelines found in the literature [16] and the ITU Recommendation 1368-3 [21] (fixed $C$, variable $I$) the following test procedure was used to measure the $C/I$ protection ratios:

1. For each of the three DTT tested receivers we measured their sensibility finding an average level of -73 dBm. Thus the wanted channel power level $C$ was set to -73 dBm. This can be considered the worst operative case.
2. The wanted channel power level was measured using the Agilent N9010A Vector Signal Analyzer (VSA) with a channel bandwidth of 7.61 MHz.
3. The signal generator transmitting the interfering DTT signal was initially set to a power level of -20 dB below the noise floor of the tested receiver.
4. The signal level of the DTT interference was then adjusted at the output of the signal generator to achieve the required degradation (PF point) of the received and decoded MPEG signal.
5. The RMS power level of the interferer was measured in the channel bandwidth of the receiver.
6. The $C/I$ protection ratio was calculated from steps 2 to 5.
7. Steps 2 to 6 were repeated for each of the channels from $N - 9$ to $N + 9$.

The protection ratios for the three DTT receivers tested (Anechoic 1, 2, 3 curves) are shown in figure 3. The results demonstrate that, even in real over-the-air transmission, the receivers under test can be considered as having typical operating performance for silicon receivers, more susceptible to DTT interference on the $N - 1$, $N + 1$ and $N + 9$ channels. The reference results found in the literature for both silicon and can tuners were obtained considering a central frequency of 790 MHz (channel 61). For this reason we chose the same centre frequency for obtaining consistent values.

The protection ratios were obtained taking into account the characteristics of all antennas and cables used in the measure setup. The measurements in the anechoic chamber present a higher $C/I$ ratio than the previous studies, due to the fact that the values were obtained in different conditions implying over-the-air transmission, as described before.

C. Spectrum Sensing Method

Spectrum sensing in the TVWS needs to detect the presence of different types of signals such as DTT or wireless microphone (WM) in a particular TV channel.

As known, spectrum sensing techniques mainly focus on primary transmitter detection and can be generally classified in three main categories: matched filter, energy detection and signal feature detection [22]. The energy detection method is based on performing a FFT and computing the squared sum of the resulting coefficients for an estimate of the power level. This value is compared to a threshold calculated using the noise and interference level present in the channel and if the estimated power level is above the threshold, the channel of interest is considered free. Cyclostationary Feature Detection [23] is a signal classification method which exploits the presence of cyclic components within modulated signals. Noise is discarded by being a stationary signal with no correlation. The limitations of the energy detectors can be compensated by the advantages of signal classification and vice-versa; therefore, especially for signals of a known type, a so-called two-stage spectrum sensing can be performed.

The present system uses an improved two-stage spectrum sensing algorithm based on our previous work [24]. The first stage performs an energy detection deploying filter banks for sub-band division and FFT for calculating signal power levels in each sub-bands. The resulting values are compared to DTT and WM specific thresholds values to mark the channels as free (“white”) or occupied. The second stage of our sensing method performs the signal classification: for all the channels that previously were identified as not “white” we analyze if they are occupied by PU or SU using a modulation classifier. The modulations for DTT (QPSK, 16QAM, 64QAM etc.) and WM (FM) signals are known, so a signal classifier for these typical modulation schemes can be used. Based on the signal classification stage, the channels are completely discarded or added to the previously built white list.

D. Adjacent Decision Algorithm

As described in section II, we are presenting a system in which a central cognitive device transmits DTT-contents over the TVWS in the UHF band to DTT TV sets, avoiding interferences with existing transmission. These TVWS have to be considered as interferers to all DTT receivers present both in the home environment as in the nearby environment (for example neighbor apartments of a house).

![ADA Mask Protection Ratios](image)

Fig. 4. ADA Mask Protection ratio calculated based on the measurements performed in the anechoic chamber

Thanks to the previous measurements we obtained information of how DTT receivers can be interfered by active transmission over their adjacent channels. From the point of view of a potential transmitter operating in one of these adjacent channels, the $C/I$ protection ratio in figure 3 can be turned into a mask to be used for calculating the allowed transmission power. This mask is the reversed representation of the protection ratios of figure 3: the superior adjacent channels of a transmitter represent inherently the inferior
adjacent channels of a potential receiver and vice versa, the inferior adjacent channels of a transmitter represent the superior adjacent channels of a receiver, as shown in figure 4.

For choosing the best available TVWS and avoiding at the same time interference to the adjacent active channels we developed and implemented a decision algorithm called Adjacent Decision Algorithm (ADA). The inputs of the algorithm are the occupancy data (the list of available channels obtained from the joint exclusive use of GL-DB and a spectrum sensing method), the channel power values in the UHF band (two-stage spectrum sensing), the number of channels to be used (from the DMUX/S-TRAN/MUX block) and the adjacent channel protection ratio mask (ADA Mask Protection Ratio) shown in figure 4.

We assume that a number of $N$ free channels can be detected. The $N^{th}$ available channel can be seen as a potential interferer by its 18 adjacent channels (from $N - 9$ to $N + 9$ channels). In the same way, a generic $(N \pm x)^{th}$ channel (with $x$ from 1 to 9), sees the $N^{th}$ free channel as its $(N \mp x)^{th}$ adjacent channel. Based on the knowledge of both the received power of all the 18 adjacent channels and the ADA Mask Protection Ratio (figure 4), the ADA algorithm estimates 18 different potential transmission power values for the $N^{th}$ free channel. Only the minimum power value guarantees an active transmission on the specific channel avoiding interferences with all its 18 adjacent channels.

Multiple low-power secondary transmissions behave as a single high-power user when they all are using the same frequency. Nevertheless, in a realistic indoor scenario with more than one secondary user, simultaneous secondary transmissions will have inherently different transmit powers and will operate in different frequencies. Thus, their aggregated transmit powers cannot be simply summed up and treated as a single high-power interference. Measurement results [25] showed how the tolerable interference level in a particular adjacent channel decreases when multiple devices access different adjacent channels at the same time.

Based on the number of channels used to retransmit the selected HDTV contents and a specific correction factor [25], ADA is able to find the TVWS with the highest potential transmission power level, for incrementing the performance of the indoor system in terms of coverage (distance) between a transmitting and a receiving device. A schematic block diagram of ADA is shown in figure 5.

### IV. MEASUREMENTS AND RESULTS

During the second part of our research we investigated the coverage of the central device in a real indoor environment performing a DTT MUX retransmission considering the center frequency and the transmission power level (fixed) of the free channels obtained by using the described ADA algorithm.

#### A. Set-up

The set-up for the measurement campaign consisted of a broadband vertically polarized omni-directional discone antenna connected to a DTT compliant TV set, and two USRP2 SDR boards connected to two PC running a software model that commands the RF hardware and singularly implement the entire baseband processing. Each board is connected to a vertically polarized off-the-shelf omni-directional indoor antenna. One of the boards is used as the main central cognitive device, while the second one, placed in an adjacent room, plays the role of another multi-vision system transmitting continuously for simulating the aggregate interference scenario. The main central cognitive device of the proposed system (figure 6) is performing following tasks:

- running a decision algorithm (ADA) considering all adjacent channel interferences for choosing the optimal transmission frequencies and power levels;
- transmitting a DTT signal using the selected frequencies.

The indoor measurements were performed inside the Department of Electric and Electronic Engineering (DIEE) located in Cagliari, Italy, using the 474 - 858 MHz frequency range (Italian DTT spectrum). The central device and the interference board are considered to be fixed in location during all the tests, while the receiving TV set has a variable position. We selected the position (figure 7) of the central device investigating the received power channel levels in different locations of the department in order to find the worst received signal conditions.

The central cognitive device, using the ADA, calculated the maximum available transmission power for the selected best TVWS. By initially placing and operating a TV set close (more than 1.5 m to avoid antenna coupling) to the central cognitive device, we checked for interference with the received existing transmissions, ensuring the correct functionality of the ADA. Thus, by maintaining this fixed transmission power level, no other receivers, placed in a more distant position, can be disturbed by a new transmission.

From this moment the only variable during the measurement campaign was the distance between the central device and the receiving TV set.

For the investigated worst-case scenario a transmission power of -22 dBm for the central device, operating on channel 46 (674 MHz), was calculated by ADA in order to not disturb a receiver in proximity of the central device and to avoid the effects of aggregated interferences with another multi-vision
system. This power level is the output power level of the central device, prior to the antenna used for the effective transmission.

Fig. 6. Schematic of the hardware set-up for the central device

B. Measurements

Initially we considered the TV set on the same floor (ground floor) with the central device. We subsequently changed the TV position until reaching the coverage limit using the same subjective evaluation criteria, the absence of a PF, used in the previous paragraphs. We started by positioning the TV set in the neighbor room of the central device reaching a distance of 5 meters. Incrementing the distance from the central device we found two position of the coverage boundary. The slight difference in linear distance, 20.5 meters (TV1 in figure 7) vs. 19 meters, is motivated by the presence of a different number of walls in the two links, specifically the presence of one supplementary wall for the TV set positioned at 19 meters from the central device. Subsequently we positioned the TV set in different positions on the first floor of the building (figure 7), keeping the same position and transmission power for the central device as in the previous scenario. We changed the TV position until reaching the coverage limit using the same subjective evaluation criteria, the absence of a PF. On the second floor we positioned the TV set in the room directly above the central device reaching a distance of 6 meters (TV4 in figure 7). We increased the distance from the central device and found the coverage boundary, corresponding to the TV2 position in figure 7, at 16.5 meters.

The peculiar characteristics of the chosen environment (ceiling height of 6 m and wall thickness of 1 m) make the propagation characteristics implicitly worse than for a residential environment. For these reasons, we can conclude that the coverage of the presented system is optimal for the extent of a normal two-floor house.

V. APPLICATION SCENARIOS

In this section we present different application scenarios for our HDTV multi-vision system described in the previous section.

A. DTT contents redistribution

The first scenario is an indoor short-range distribution system for the wireless retransmission of free-to-air and PPV DTT contents, redirecting several PPV channels from different DTT MUXs in a centralized manner, with only the central cognitive device and subscription. The great advantage to existing systems, as for example MoCA, is that the end TV devices do not require any changes or additional set top boxes. Only a central decoder will be essential to allow users watching their PPV contents everywhere in their desired environment.

B. Satellite contents redistribution

The second scenario is similar to the previous one: an indoor short-range distribution system for the wireless retransmission of satellite contents received by the cognitive HD device. The central cognitive device receives the contents of n satellite transponders instead of n DTT MUXs.

Additionally to the first scenario, dedicated exclusively to the indoor redistribution of PPV DTT contents, the satellite version can enable DTT TV sets to view also satellite contents without any supplementary hardware components.

C. Auxiliary and mixed content redistribution

The previous application scenarios can be approached also in a combined manner, for example by mixing satellite and/or DTT TV contents The appropriate RF/BB modules can be randomly combined and replicated in order to meet any particular scenario. Furthermore, additional contents from external DVD/PC/mobile/camCORDERS or IPTV devices can be fed into the central device and combined with the mixed content, for enhancing flexibility of the system and making it feasible for a wide variety of consumer applications.

We need to underline that, for all the described scenarios, unauthorized access can be prevented by employing scrambling techniques implemented on a smartcard inserted in the CI slot of the TV receivers [26].

Fig. 7. Indoor application scenario: one central cognitive device broadcasts a DTT signal to four TV sets situated on different floors
VI. CONCLUSIONS AND FUTURE WORK

This paper proposes an indoor short-range distribution system for the wireless retransmission of SD and HD DTT-compliant contents in the free TV channels. A central device can simultaneously and independently distribute the TV contents to several TV sets located in different areas of a building. The system architecture is based on a joint use of GL-DBs, two stage spectrum sensing and EIRP control techniques to provide accurate protection to incumbents. Communication between server and clients is performed over the identified free TV channels using the existing DTT standards. Unauthorized access can be prevented by using DRM scrambling techniques via the CI slot of the TV receivers.

To obtain a valid proof-of-concept for the proposed system we first investigated the issues related to the allowable maximum EIRP useful to transmit without providing harmful interference (ACI) and quantified them not only for the first adjacent channel. Starting from already performed investigations on commercial DTT receivers, we conducted our own measurement campaign with newer receiver types and in real working conditions, over-the-air transmission. These tests were performed in an anechoic chamber using antennas for the transmission of the wanted TV and interference signal. We obtained the protection ratios for over-the-air DTT transmissions, revealing a slightly higher C/I ratio than the previous studies. For dynamically choosing the best free channel, in order to avoid interference to the adjacent active channels, we designed a particular algorithm called ADA. The algorithm uses as input the occupancy data obtained from the Agilent VSA and the adjacent channel protection ratio mask, in order to obtain a list of useful frequencies and transmission powers.

Based on these transmitting power values calculated using the ADA algorithm, we used the second part of our research study to experimentally determine the conditions under which the co-existence of DTT receivers and short-range transmitters is feasible for indoor environments. Taking into account all the elements related to the presence of typical attenuation phenomena for an indoor environment, we investigated the coverage distance between the central device and a DTT receiver, using a fixed transmission power level. The implemented hardware test-bed is based on commercial TV sets with integrated DTT tuners and off-the-shelf antennas in combination with SDR hardware devices on which the system prototype has been implemented. The results of the indoor measurement campaign revealed an extended coverage of the wireless system suitable for a normal two-floor house. We ensured that no other receiver can be disturbed by a new transmission by respecting the transmission protection ratio in order to firstly not disturb the potential receivers in proximity of the central device.

By implementing a functional prototype of the proposed system and performing an extended indoor measurement campaign we delivered the proof-of-concept of the proposed indoor short-range distribution system for the wireless retransmission in the free TV channels of DTT-compliant contents. The measurements and assumptions were made using always the worst-case scenario which nevertheless delivered first satisfactory results. Future work will include the possibility to enhance the system’s coverage by improving transmission protection ratio using different modulation techniques and different antenna polarization.

REFERENCES

Mauro Fadda (M’11) is a PhD student in Electronic and Information Engineering from the University of Cagliari/Italy. He received the M.Sc. degree in Telecommunication Engineering in 2006 from the University of Bologna / Italy. In 2007 he spent one year as a researcher at the C.N.R. (National Research Center) in Bologna developing UMTS mobile-network simulation software. In 2008 / 2009 he was a researcher at the Sardegna Ricerche (Research Center of Sardinia) in Pula / Italy implementing different web communication applications. Mr. Fadda has as main research topics of interest telecommunications, multimedia and wireless sensor networks.

Maurizio Murroni (M’01) graduated (M.Sc.) with honors (Summa cum Laude) in Electronic Engineering in 1998 at the University of Cagliari and in the same year he received an award for his thesis from Telecom Italia, Inc. He has been an Erasmus visiting student at CVSSP Group (Prof. Maria Petrou), School of Electronic Engineering, Information Technology and Mathematics, University of Surrey, Guildford, U.K. in 1998 and a visiting Ph.D. student at the Image Processing Group (Prof. Yao Wang), Polytechnic University, Brooklyn, NY, USA, in 2000. In 2001 he received his PhD degree in Electronic Engineering and Computers, from the University of Cagliari. In 2002 he became Assistant Professor of Communication at the Department of Electrical and Electronic Engineering (DIEE) of the University of Cagliari. Since the 1998, he contributes to the research and teaching activities of the Multimedia Communication Lab (MCLab) at DIEE. In 2006 he has been visiting professor at the Dept. of Electronics and Computers at the Transilvania University of Brasov in Romania and in 2011 at the Dept. Electronics and Telecommunications, Bilbao Faculty of Engineering, University of the Basque Country (UPV/EHU) in Spain. Since October 2010 he is coordinator of the research unit of the Italian University Consortium for Telecommunications (CNIT) at the University of Cagliari. His current research focuses on Cognitive Radio system, signal processing for radio communications, multimedia data transmission and processing.

Dr. Murroni is a member of IEEE, IEEE Com Soc, IEEE BTS, IEEE DySPAN-SC and 1900.6 WG.

Vlad Popescu (M’12) received the M.Sc. degree in Electronics and Computer Engineering in 1999 and the PhD degree in Telecommunications in 2006, both from the Transilvania University of Brasov / Romania. In 2000 he spent four months at the University of Malmo in Sweden specializing in Multimedia applications. In 2001 / 2002 he spent one year as a research fellow at the Technical University in Aachen, Germany. In 2004 / 2005 he returned to Aachen at the same University to finish the experimental part of his PhD studies on wireless communication in underground environments. In 2009 he has been visiting professor at the Department of Electrical and Electronic Engineering of the University of Cagliari. Dr. Popescu is since 2000 with the Department of Electronics and Computers, Transilvania University of Brasov / Romania, currently as a senior lecturer. He also collaborates close with the Department of Electrical and Electronic Engineering of the University of Cagliari / Italy both on research and didactical level. His main research topics of interest are telecommunications, cognitive radio systems, multimedia applications and data acquisition.